Core Products
What are the possibilities?

Feb. 8-10, 2005

Action from the First Meeting

Examine programmatic/implementation options of using common/multiple surface and orbiting platforms (e.g., multiple MSL & MTO) to achieve fiscal efficiency while being responsive to a vibrant science strategy. Specifically address how MSR can capitalize on MSL investment to make MSR more affordable.

Naderi (Lead), Adler, Braun, Dorfman,
Lee, McCuistion, Squyers, Theisinger

Impetus for Today’s Presentation

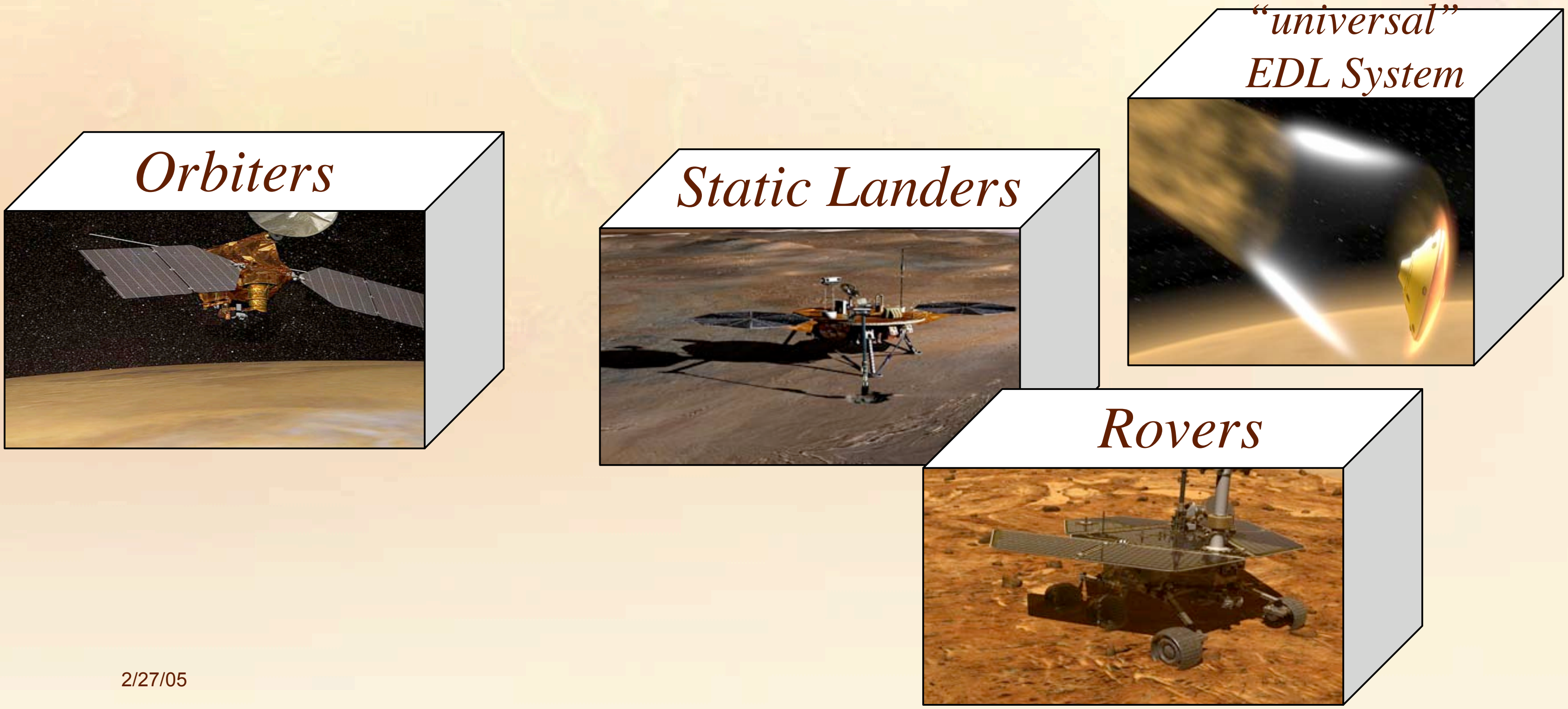
- Early Results from the MSR Pre- Project

- Core Product Action Item from the Mars Roadmapping Committee

- Today’s Presentation

Missions Sequence — Built Out of Building Blocks

- *Core products considered :*
  1. *A universal EDL*
  2. *MSL line of rovers*
  3. *Static Landers*
  4. *An orbiter platform — MRO/MTO derivative*



Customer Missions for Core Products

- Customers for core products are assumed to be :
  - The Core strategic missions
    - MSL,
    - MSR,
    - AFL,
    - Deep Drill,
    - Human Precursor Platforms,
    - MTO
  - But not Scouts
    - Too many possibilities
    - Last competition resulted in:
      - An orbiter
      - A lander
      - A airplane
      - Atmospheric sample return sample

Topics Discussed

1. Common Orbiters
2. Universal EDL
3. Common Static Landers
4. Common MSL-class Rovers
5. MSL/MSR Commonality
6. Potential Mission Scenarios

What you are going to hear

1. Orbiters: a great deal of commonality possible
   - Issue: Desire to compete at every opportunity vs going to the the supplier with previous heritage
   - Infrequency of occurrence

2. Static Landers: A great deal of commonality possible
   - Same two issues as above

3. Rovers: Multiple copies of MSL
   - Issues: mass, planetary protection requirements, cost

4. EDL: Possibility for a universal EDL but we need to overcome several challenges
   - In MER (actual) and MSL (estimate) ~ 40% of the cost of the flight system is in EDL

What you are going to hear (cont'd)

Challenges of EDL

- *We are now getting into applications that need to land up to 7 times more useful mass (compared to ~180kg of Spirit and Opportunity) on Mars*
- *Atmospheric challenges*
- *Altitude: we have only landed at -1Km or below so far*
  - *Want to land at higher altitudes — with large mass*
- *With all of the above, we are well over the Viking heritage capability EDL*
- *But all is not lost*

Thoughts on Common Orbiters

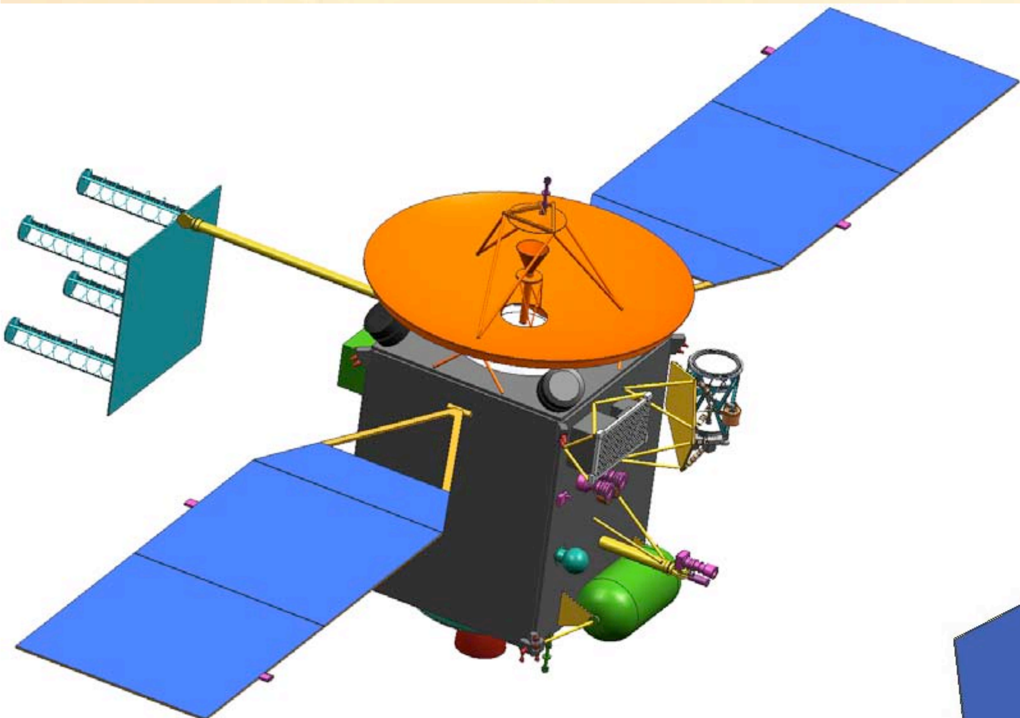
Two Classes of Orbiter

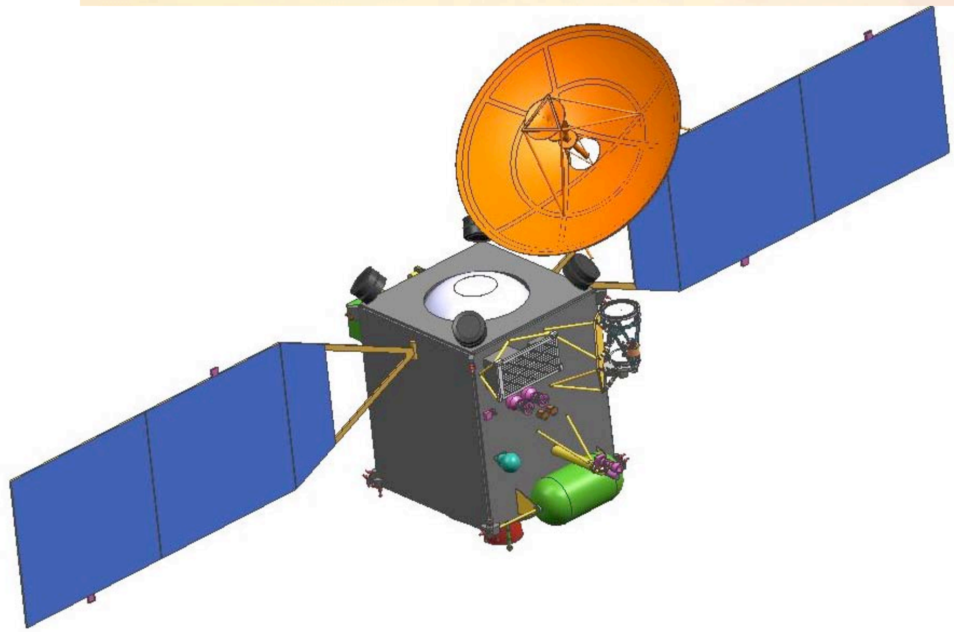
Telecom S/C

- *High Orbit (~ 4,000 km)*
- *Example MTO*
- *High gain antenna body fixed and Earth pointed*

Science S/C

- *Low Orbit (~ 400 km)*
- *Example MRO*
- *High gain antenna & S/A gimballed*
- *Science Instrument panel and Mars relay antenna nadir pointed*





Potential Applications

- Candidate Science Missions
  - Methane mapping orbiter
  - SAR mapping orbiter

- Candidate Telecom Missions
  - First MTO + technology demonstration of Laser Com, RAN
  - Second MTO + Scout Opportunity
    - 120 kg carried into high orbit or
    - 300 kg payload released prior to MOI

- MSR Orbiters

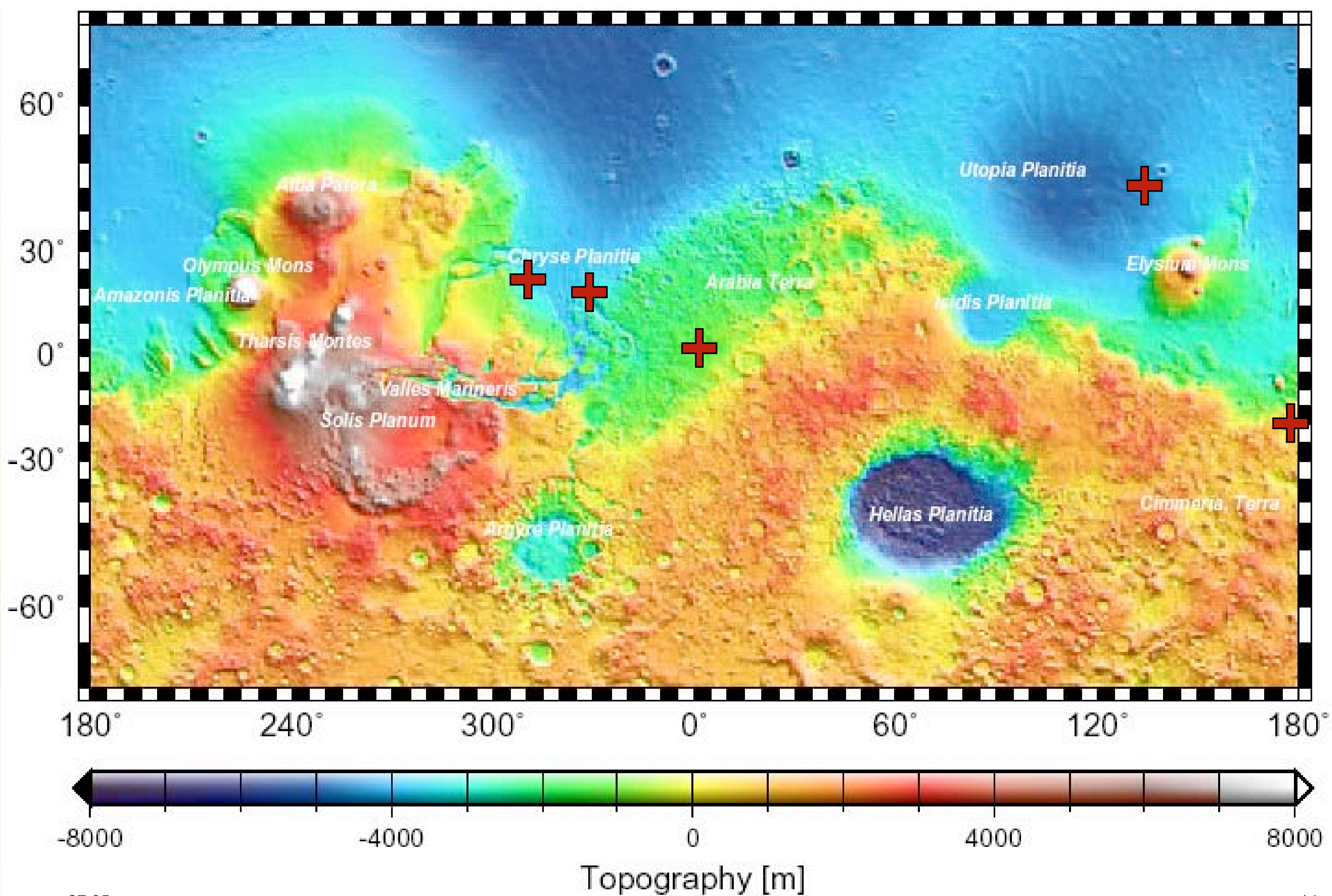
High degree of commonality at the subsystem level between all these orbiters possible

Commonality Through Free Market

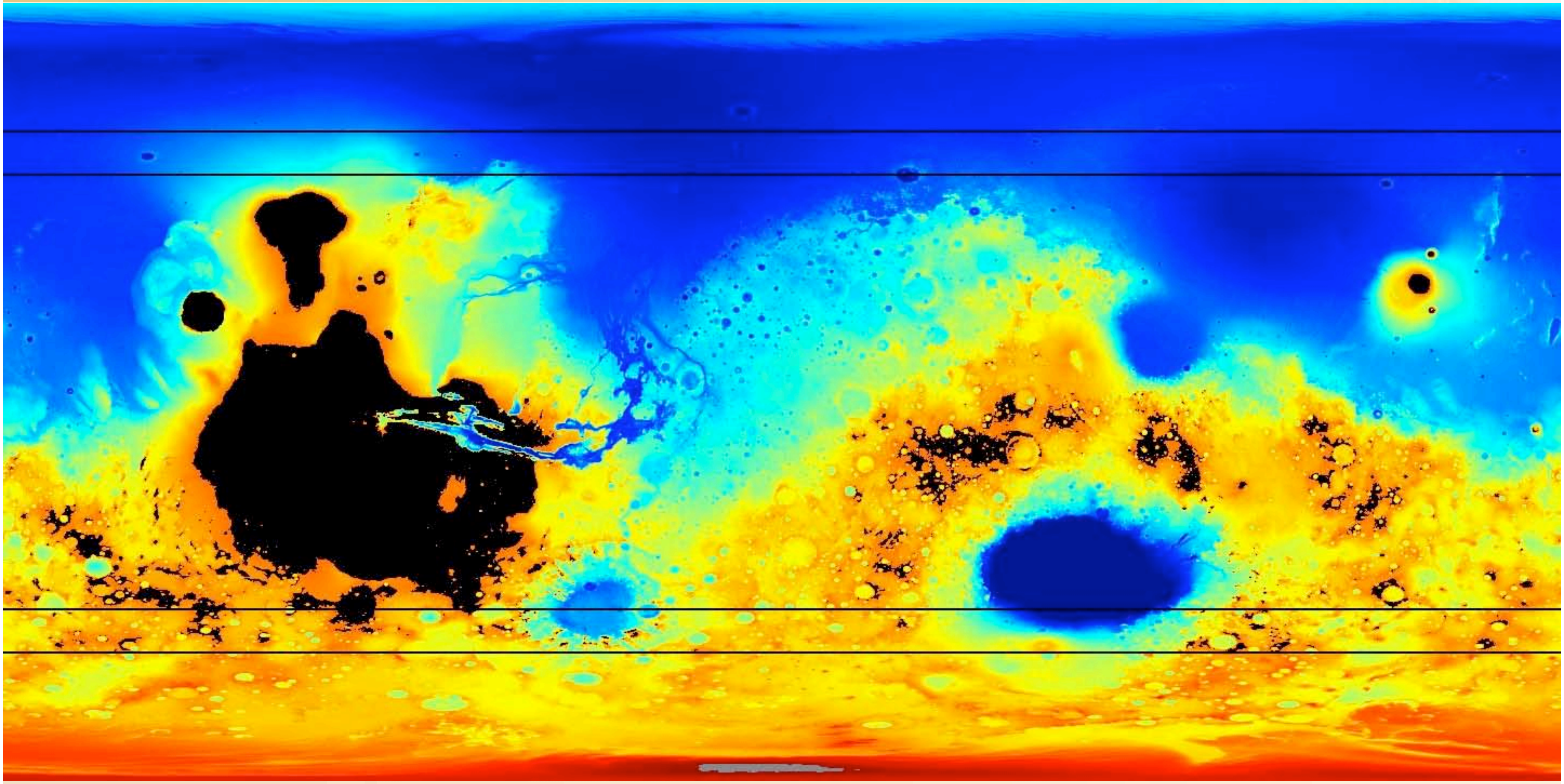
- In general use of a common platform gains fiscal savings but eliminates another desire of the NASA/OMB which is competition at every opportunity
- We used open competition RFP to solicit MTO
  - RFP released Fall 2004
  - Launch in 2009
- There is a current Mars science orbiter (MRO) wrapping up development for launch in August 2005
- It is inevitable that the MRO contractor would use commonality of subsystem to gain competitive advantage

Thoughts on a Universal EDL

Past Mars Landings



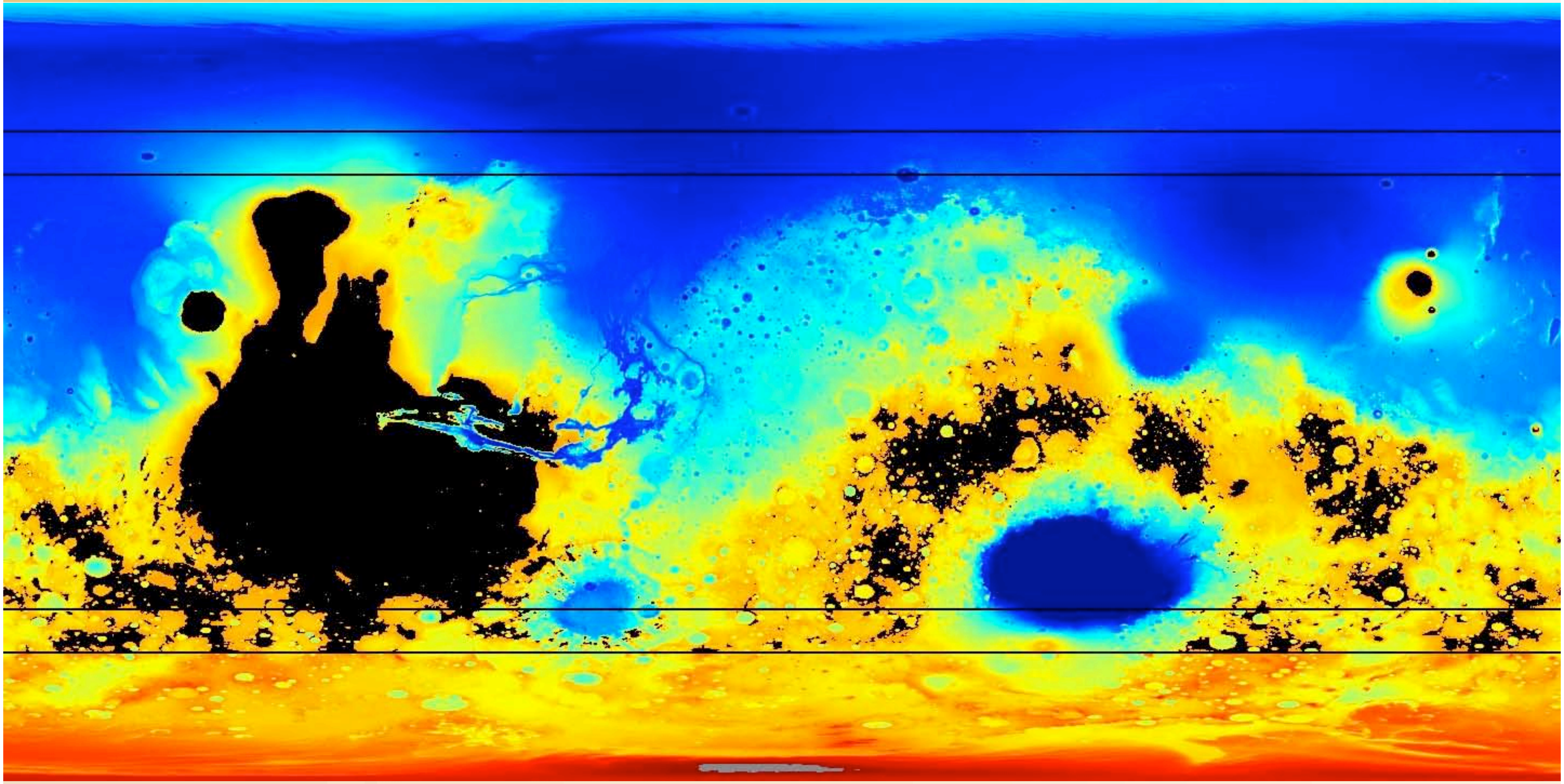
Mars above 2.5 km in Black



MOLA Topography ±90° Lat, 180° to -180°W Lon

- **Lines at ±50°, ±60° latitude**

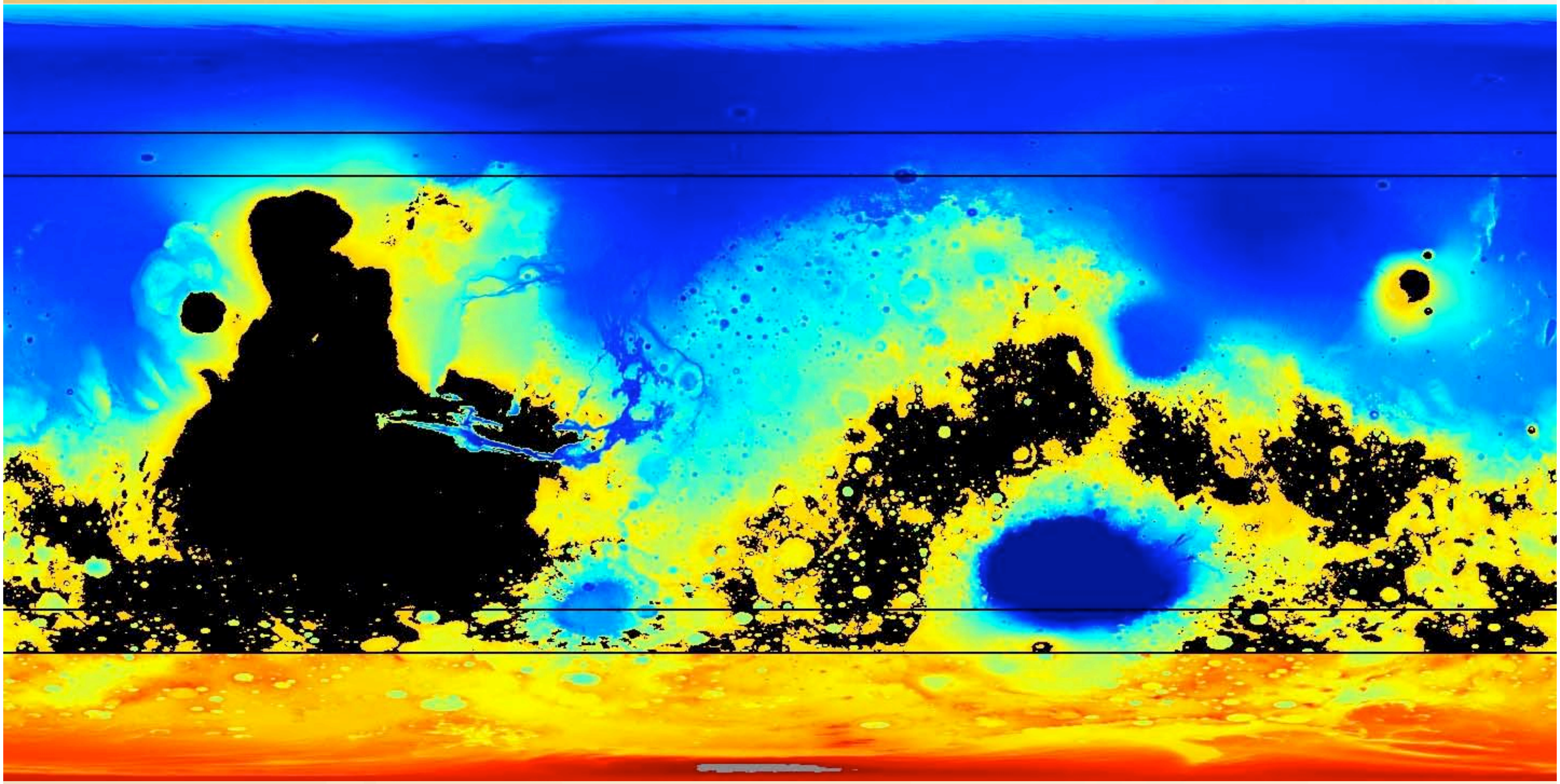
Mars above 2.0 km in Black



MOLA Topography ±90° Lat, 180° to -180°W Lon

- **Lines at ±50°, ±60° latitude**

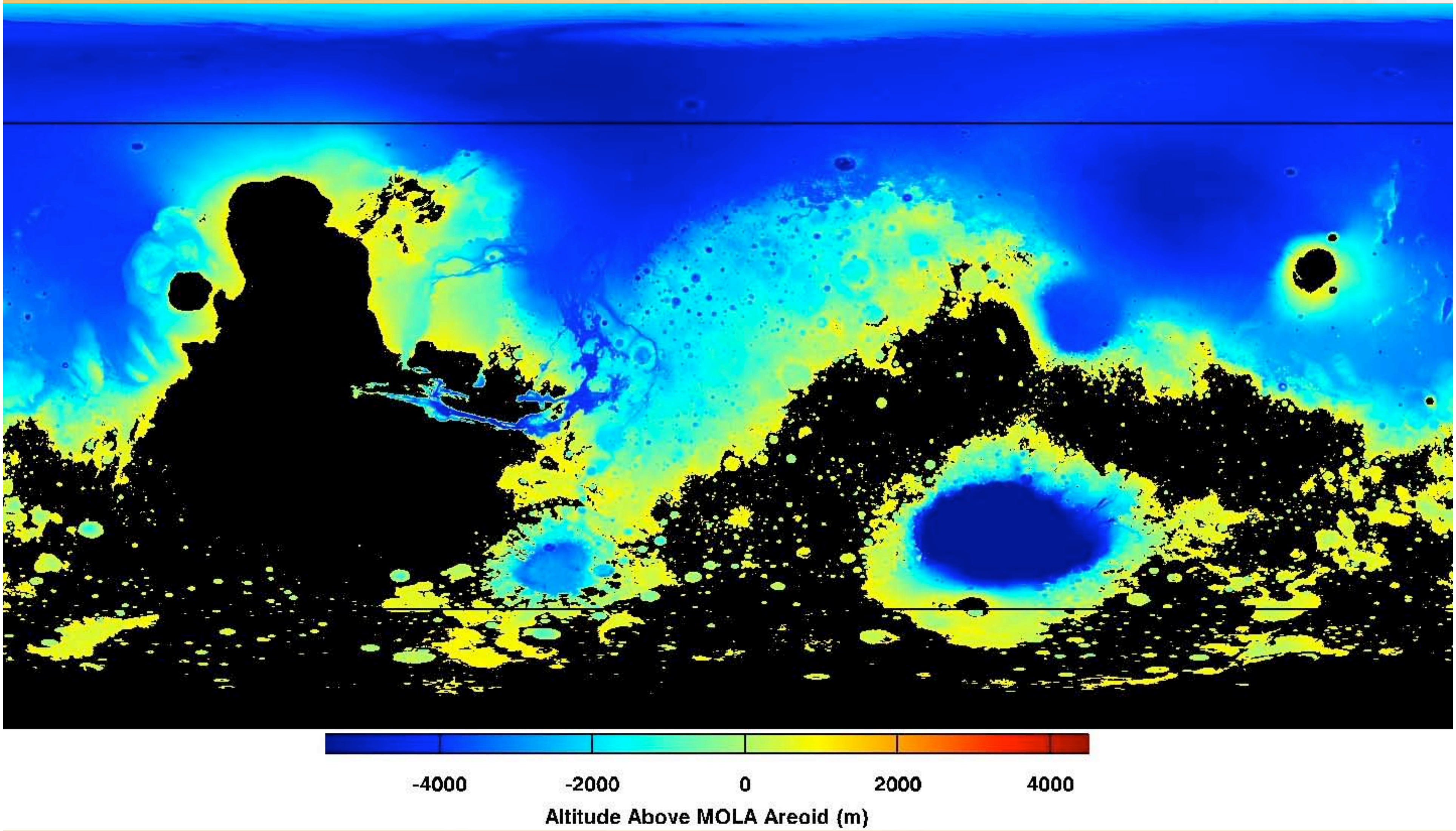
Mars above 1.5 km in Black



MOLA Topography ±90° Lat, 180° to -180°W Lon

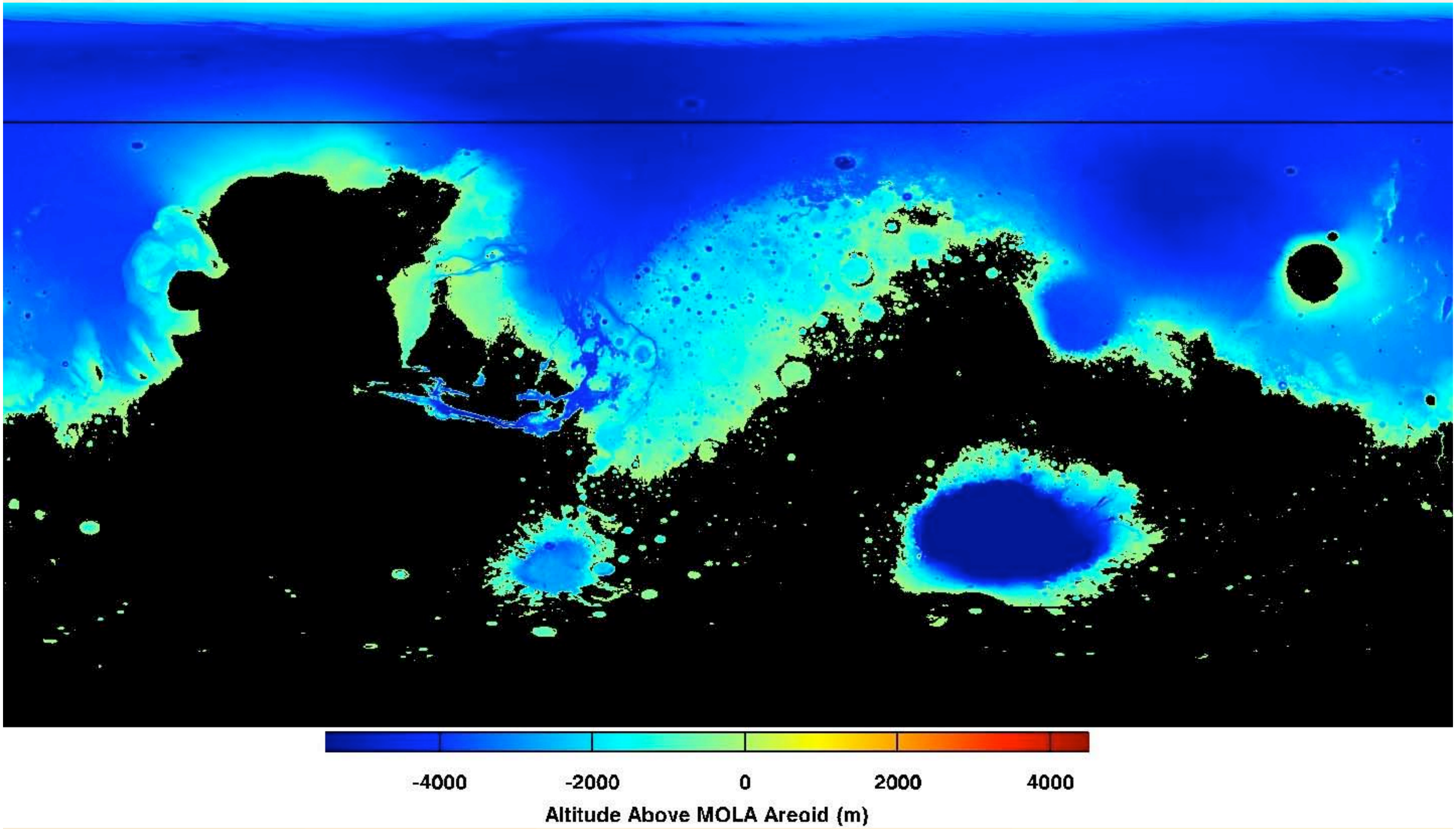
- **Black area is topography > 1.5 km**
- **Lines at ±50°, ±60° latitude**

Mars above 1.0 km in Black



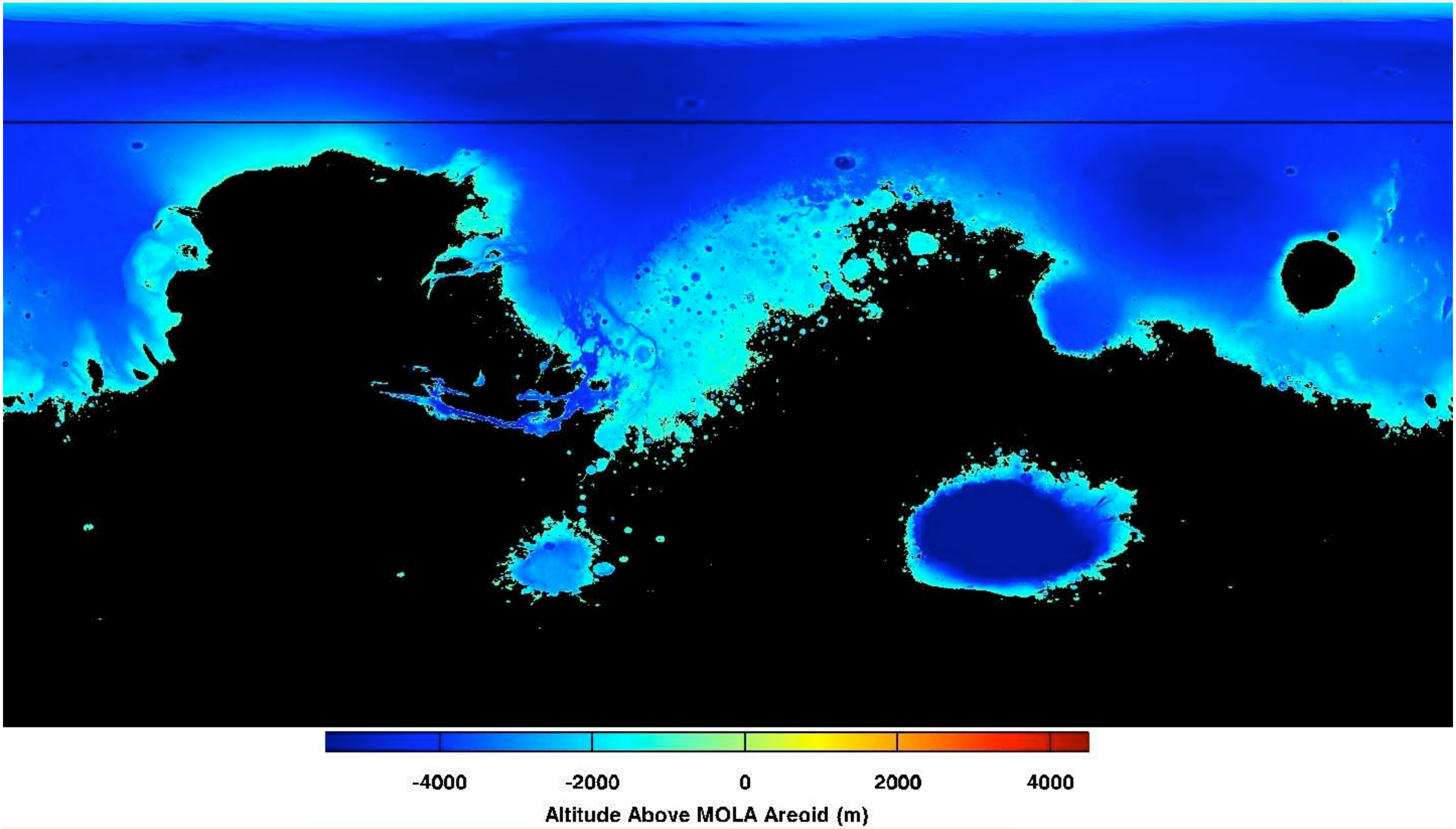
Black area is topography > 1.0 km
Lines at ±60º latitude

Mars above 0 km in Black



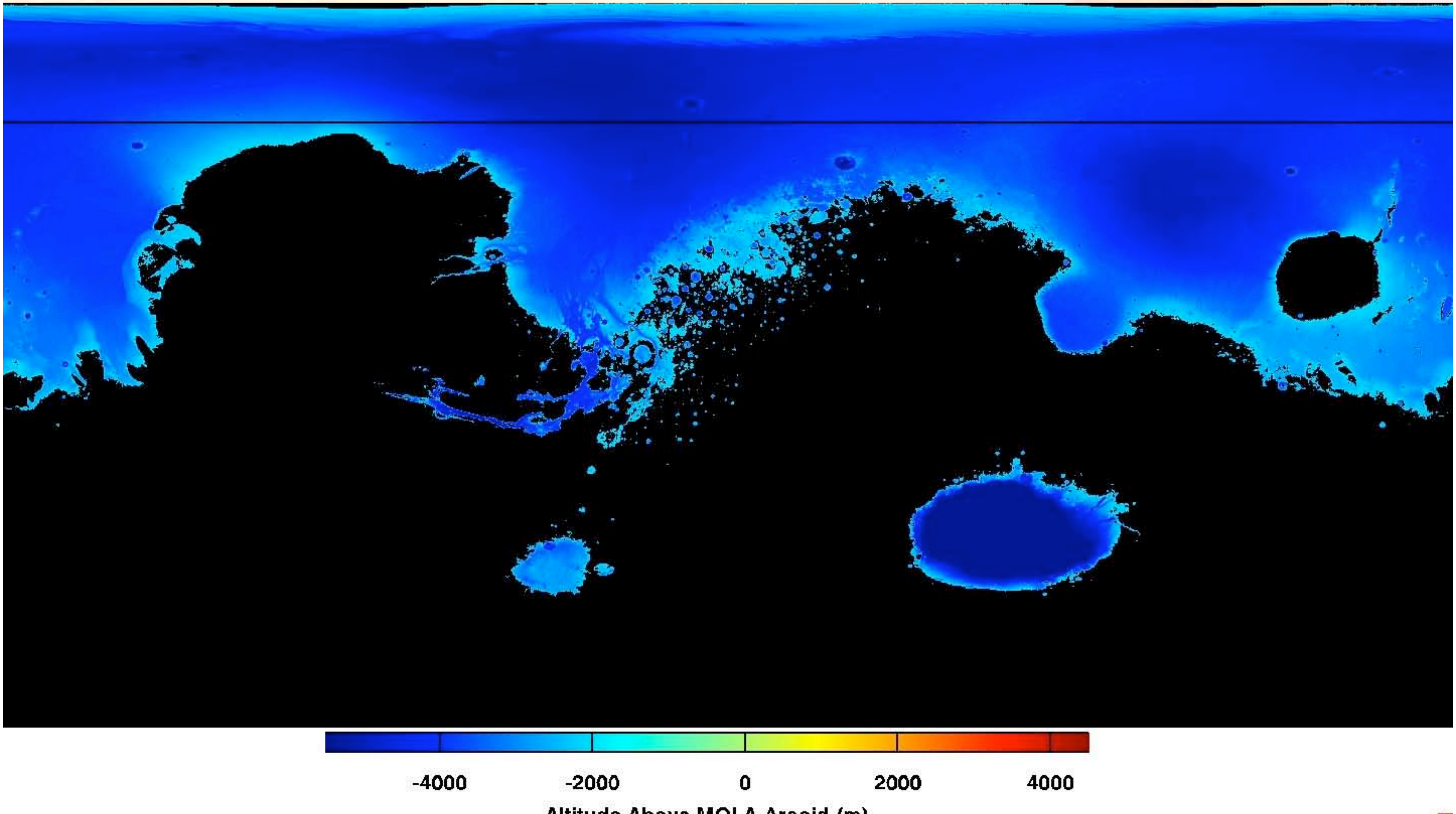
Black area is topography > 0.0 km
Lines at ±60° latitude

Mars above -1.0 km in Black



Black area is topography > -1.0 km
Lines at ±60° latitude

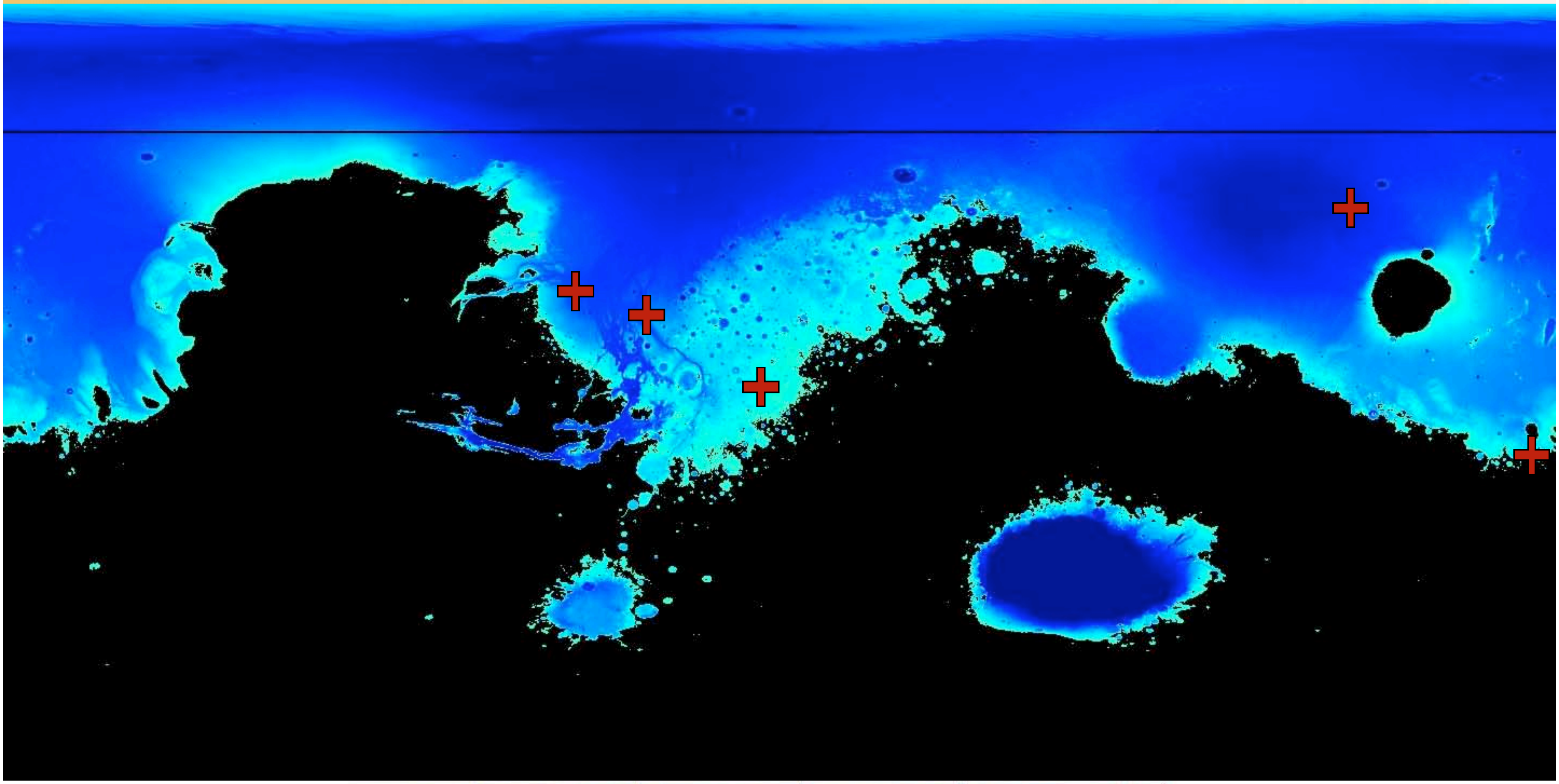
Mars above -2.0 km in Black



Black area is topography > -2.0 km
Lines at ±60° latitude

Note: Top of N. polar cap is shaded

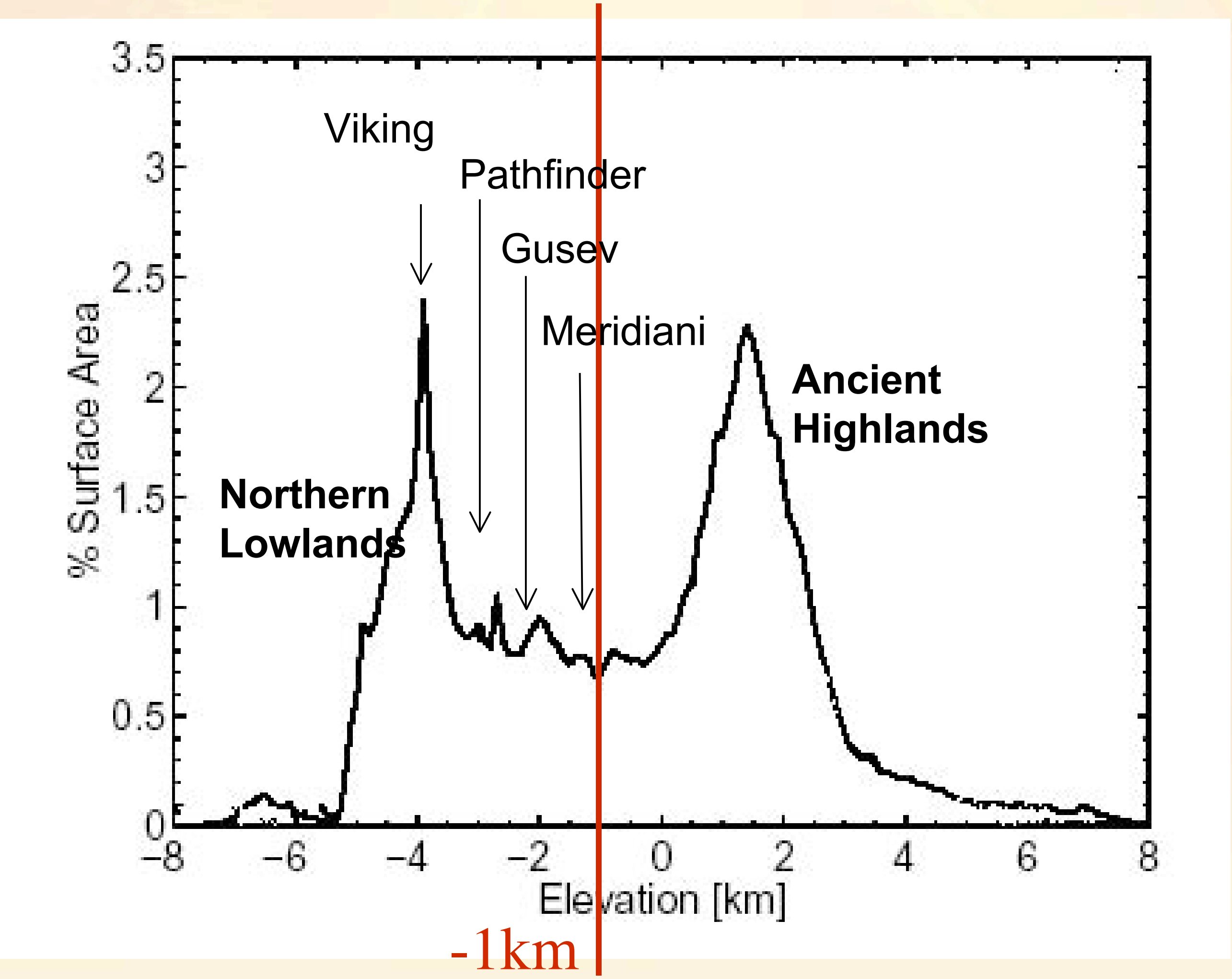
Our Past Performance -- All below -1KM



- *So far the highlands have been out of reach.*
- *What has stopped us from going higher?*

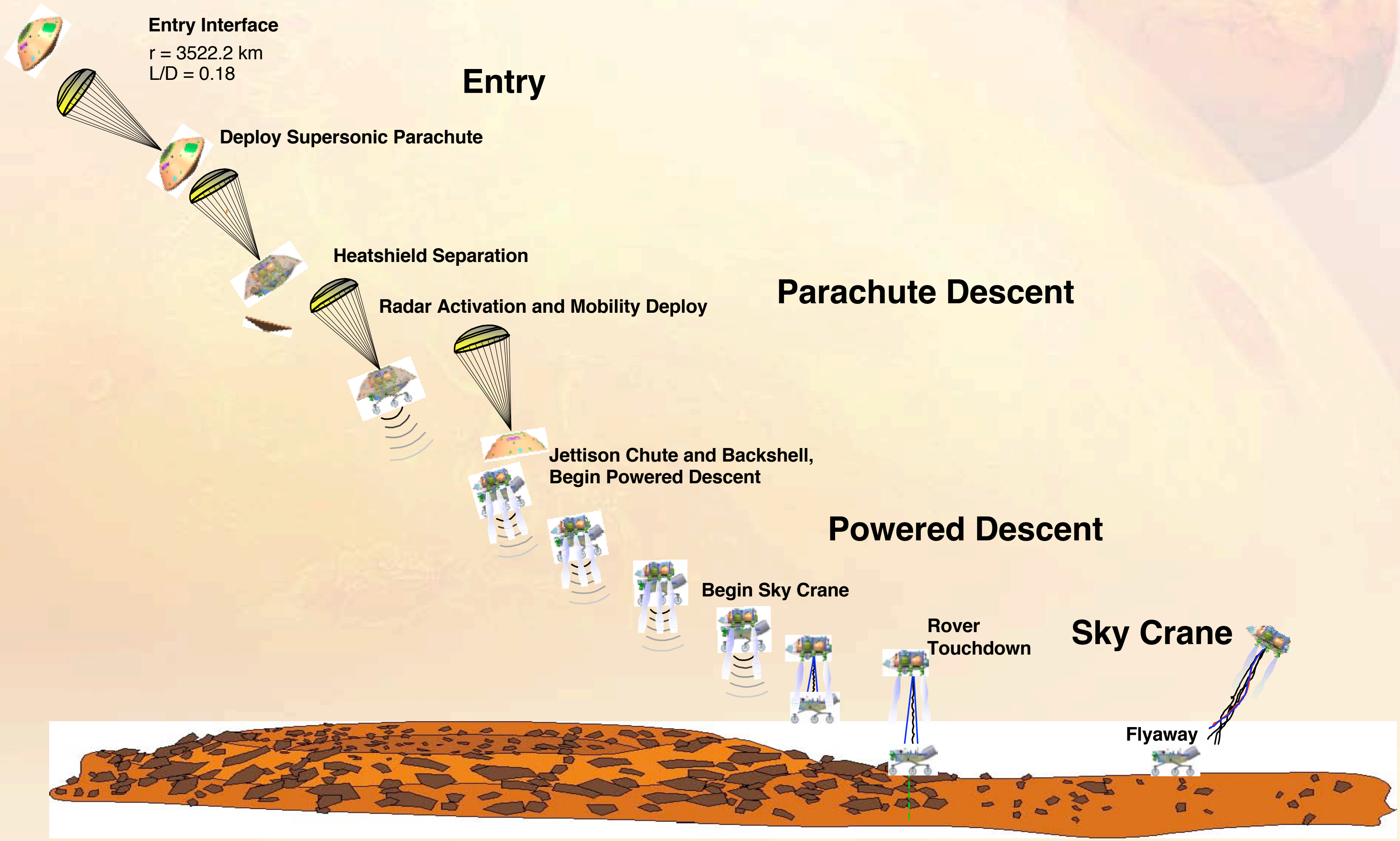
Elevation Variation

- *The highest landing to-date is Opportunity at Meridiani @ -1 km MOLA.*
- *We are still 2 km below the flanks of the Highlands.*



Topography has bimodal distribution

Skycrane Architecture

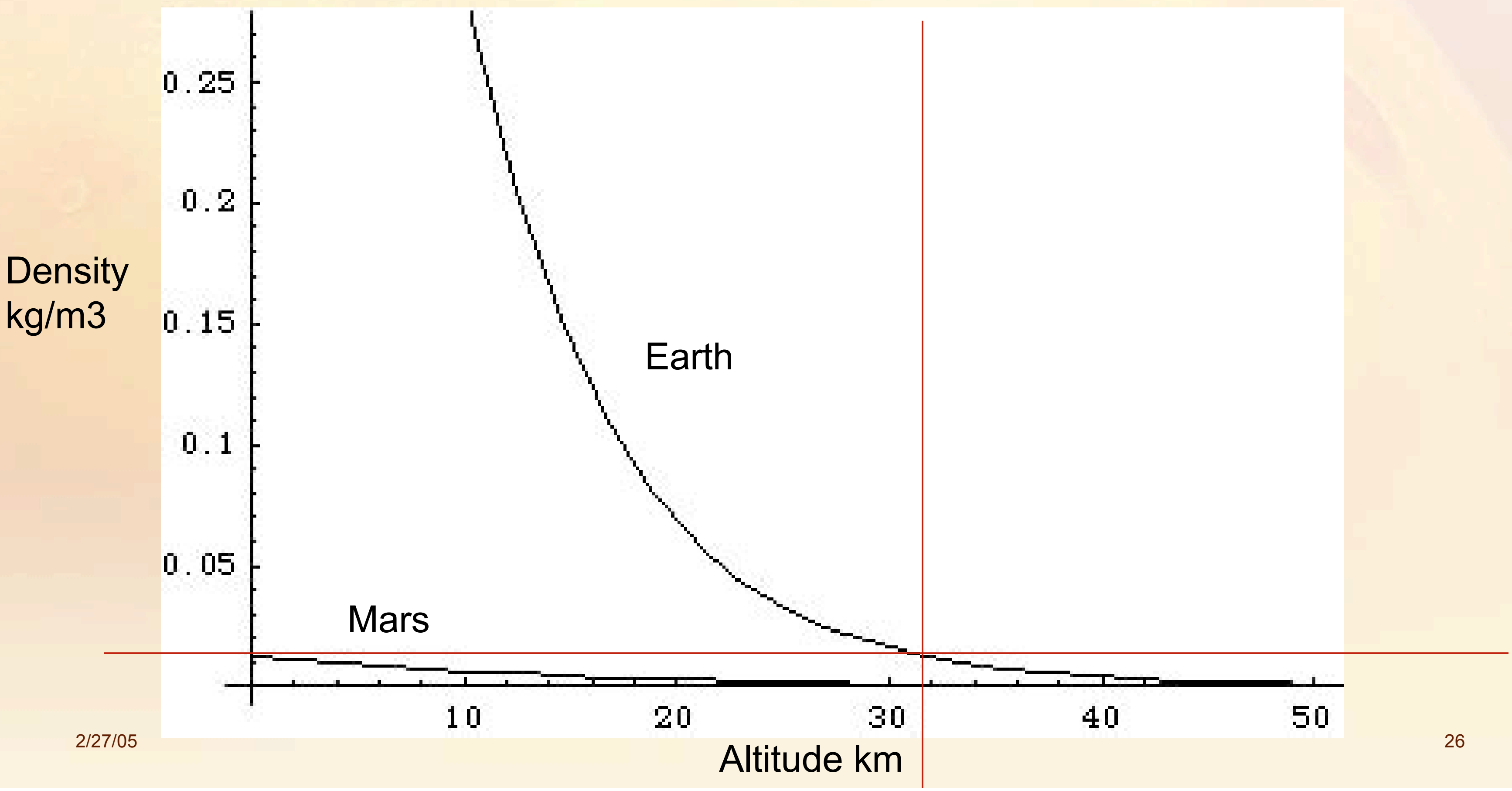


Environmental Challenges to EDL

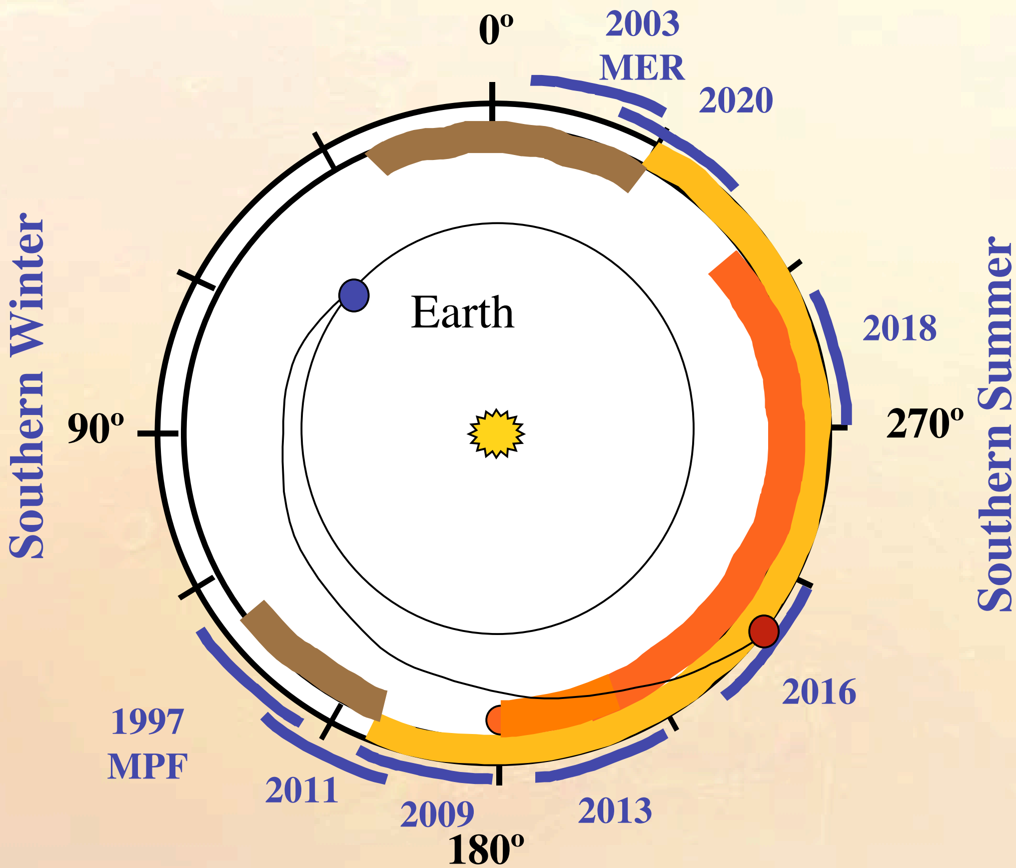
- *Low density atmosphere*
- *Dust loading of the atmosphere (or “Tau”)*
- *Seasonal atmospheric variation across opportunities*

Atmosphere Density

- *Density = 1% of Earth's*
- *Surface atmosphere of Mars has the same density as the Earth atmosphere at ~ 30km*
  - *Imagine having to land the Shuttle at 100,000 ft !*



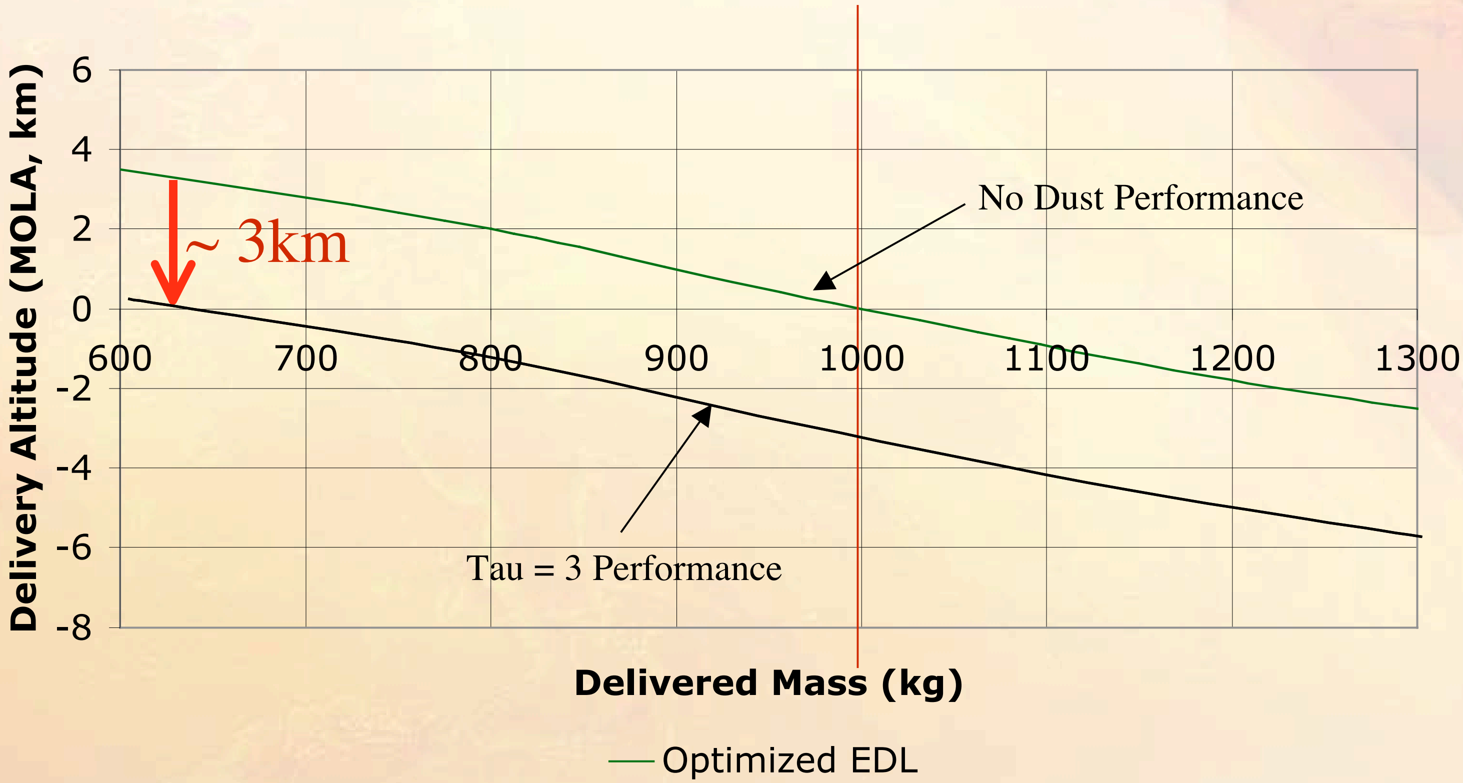
What we Know of Dust Storm on Mars



Yellow = Regional Dust Storms
Red = Planet-encircling Dust Storms
Brown = Regional Dust Storms did not occur
Local Dust Storms occur at all seasons

- *Dust changes atmospheric density profile*
- *Roughly 1 in 3 probability of a global dust storm in any given year:*
- *τ is a measure of dust in atmosphere*
  - *τ =3 is global average in a post storm season*
  - *τ >7 has been observed*

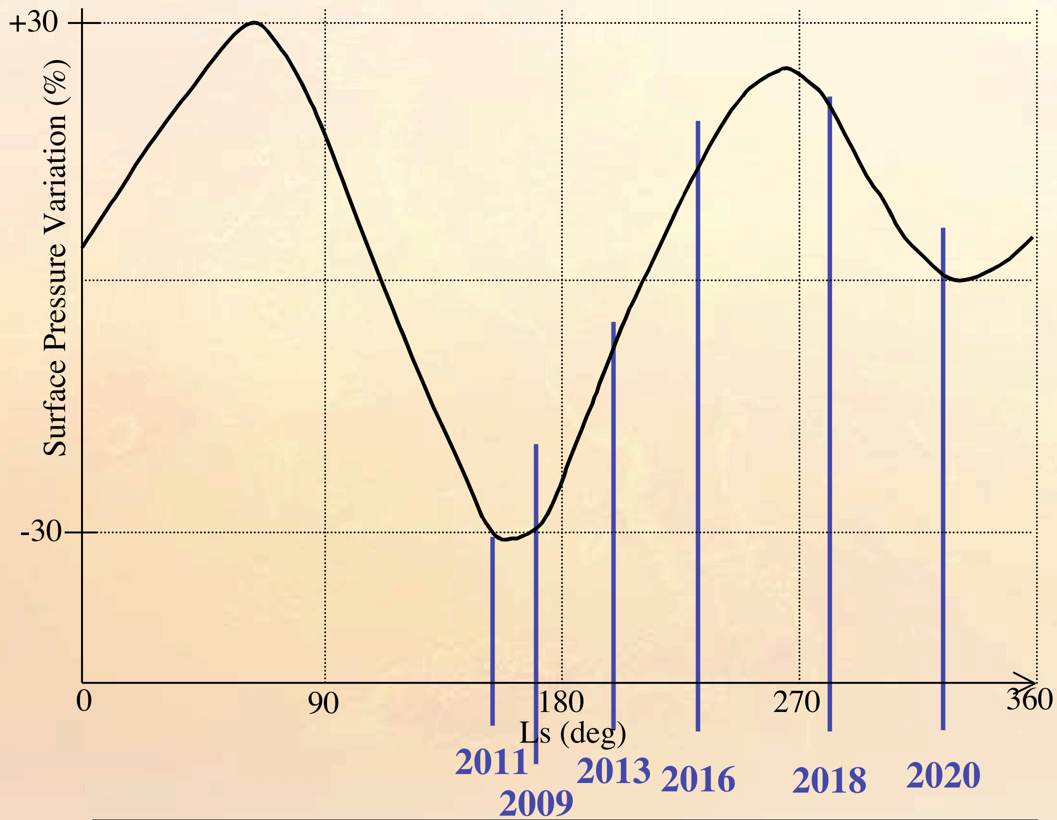
Effect of Dust in Delivered Mass vs Altitude



<u>*Assumptions*</u>

- *Performance for the 2013 opportunity*
- *Skycrane architecture, Descent Stage optimized for delivered mass*
- *Two parachute system used, Viking supersonic and 110 ft. subsonic*
- *Maximum aeroshell diameter used (5.0 m)*

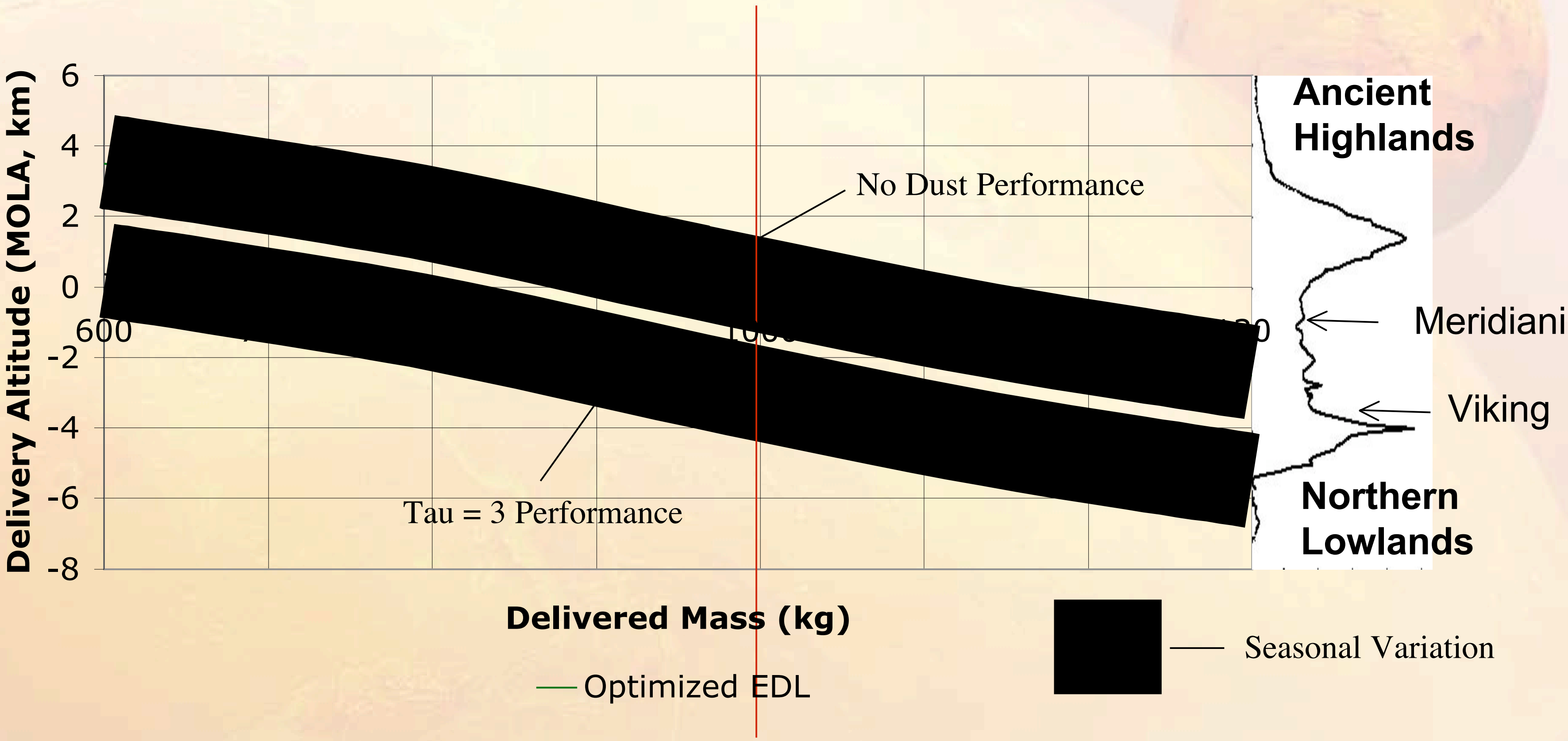
Seasonal impact on Delivered Mass vs Altitude



Northern	Summer	Winter
Southern	Winter	Summer

- *Atmosphere Variation*
  - *The amount of air drops in the winter by 30% (moves to poles)*

Effect of Seasonal variation on Delivered Mass vs Altitude



<u>*Assumptions*</u>

- *Performance for the 2013 opportunity*
- *Skycrane architecture, Descent Stage optimized for delivered mass*
- *Two parachute system used, Viking supersonic and 110 ft. subsonic*
- *Maximum aeroshell diameter used (5.0 m)*

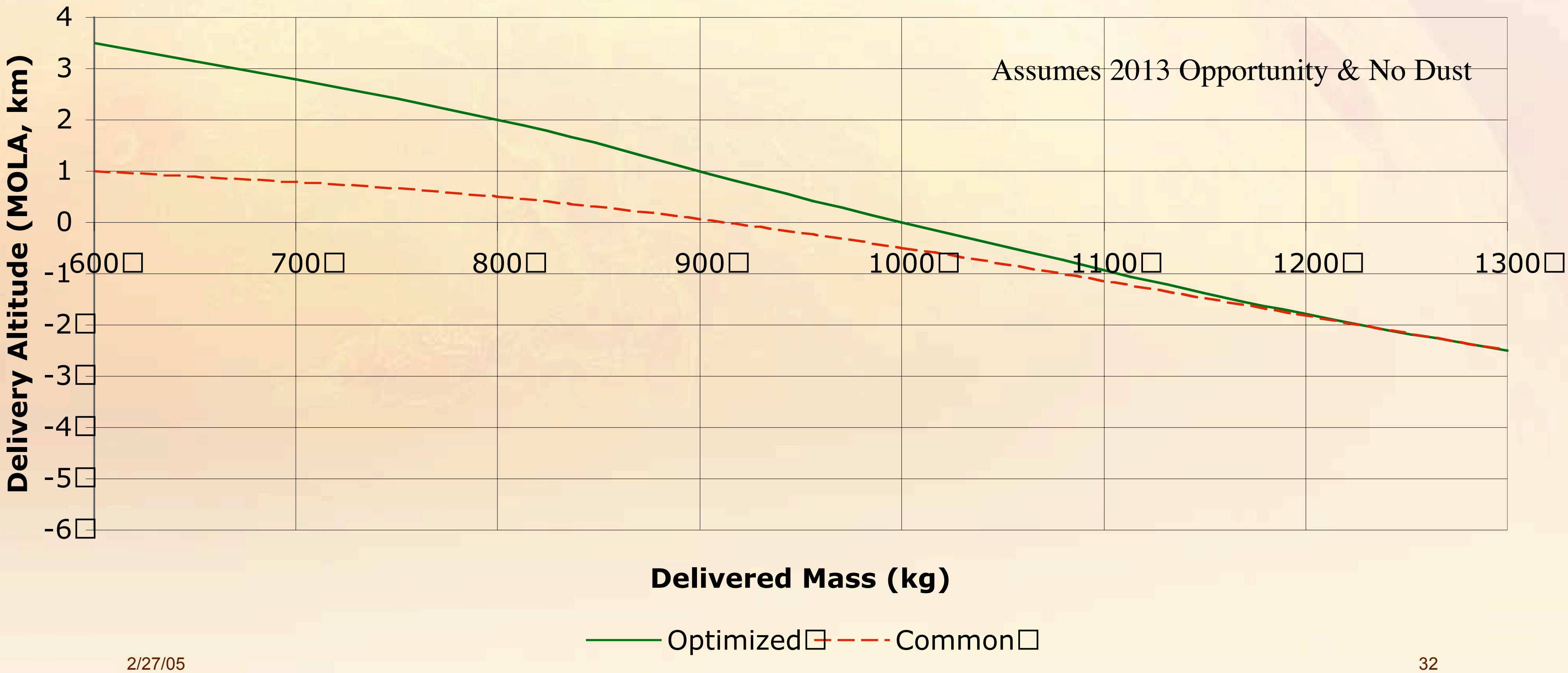
Effect of Common Design on Lower Mass payloads

- If we were to develop a common EDL system design to encompass future missions mass delivery needs MSR would be the principal driver with ~1300 kg delivered mass

- Missions with lower delivered mass needs will lose altitude performance (compared to optimal design)

"Common" Landing System Impact

- Common EDL designed around 1300kg delivered mass
- For lower masses, this system is less efficient than optimal
- But for large delivered masses, efficiency loss is small compared to environmental factors



Milking the Viking Investment

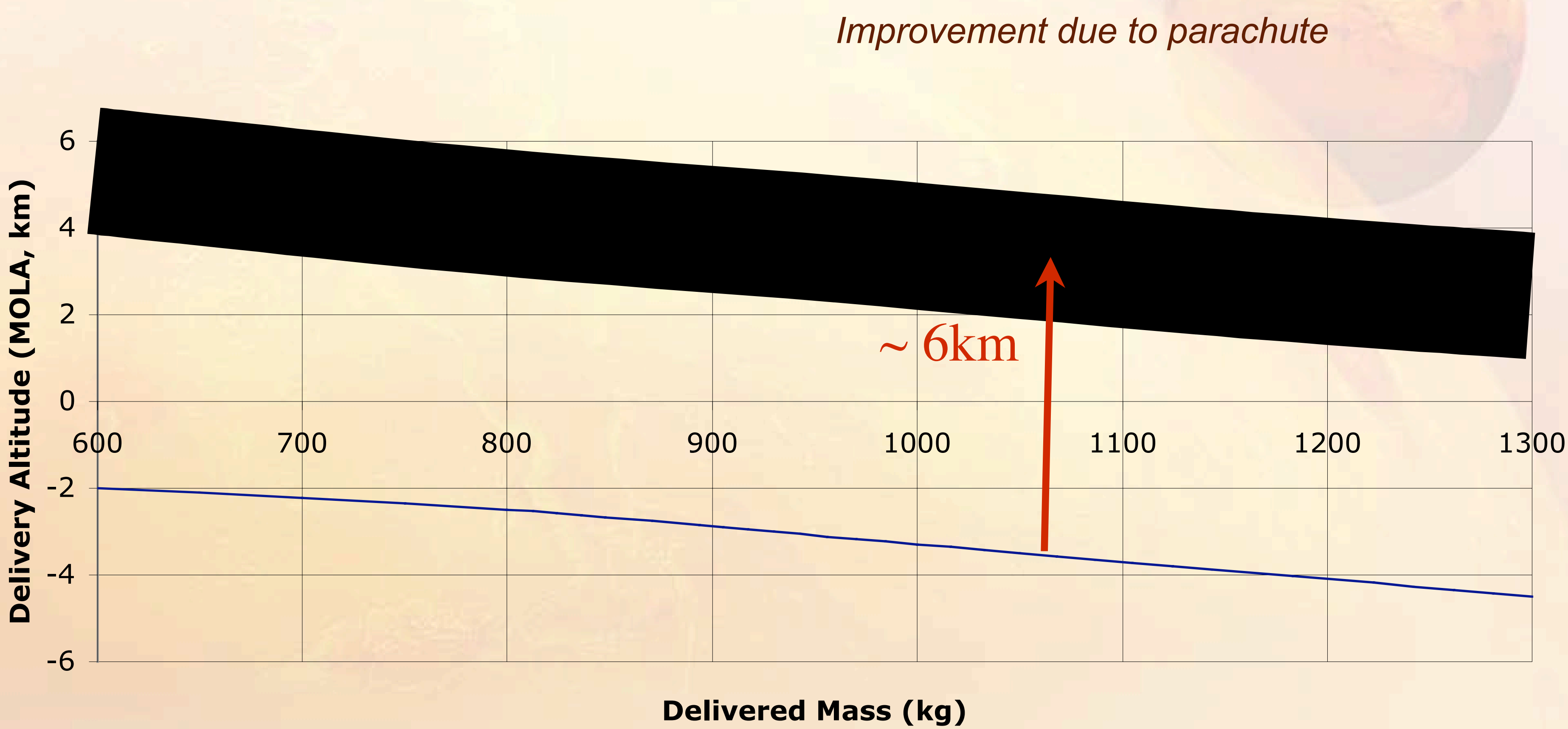
We are still living off the Viking technology investment of nearly 4 decades ago

- Entry Vehicle
  - 70 deg cone shape
  - Diameter driven by launch vehicle faring (5 m is largest available)
  - Lift to Drag Ratio as high as 0.24
- Supersonic Parachute Size
  - 16.15 m (53 feet) diameter is the largest qualified chute from Viking BLDT test program
- Parachute Opening conditions
  - Dynamic pressure limit as high as 800 Pascals
  - Mach 2.2

Breaking out of the Viking Paradigm

- Next Generation Supersonic Parachute
  - Larger parachute deployable at higher Mach numbers
  - End-to-end simulation of EDL shows that the performance gains of 6km in altitude are possible
- Larger launch vehicle fairing and heatshield diameter
  - 6.5 m LV fairing would allow for ~6.0 m aero-shell
  - Performance gains of ~1-2km in altitude possible in conjunction with larger parachute
  - Unknown impact on launch vehicle cost & performance

Altitude Capability w/Improved Parachute



- *Common EDL designed for 1300 kg delivery requirement*
- *Dust degraded performance assumed (τ = 3.0)*
- *2013 opportunity*

Orbital Entry Options

- Given the uncertainty of the dust in the atmosphere one possibility is to go into orbit and “ride it out” — a la Viking

- Orbit insertion options
  - Propulsive
  - Solar Electric Propulsion
  - Aerocapture

Cost/Benefit Comparison Orbit insertion vs Parachute

- *Parachute*
  - *Mitigates dust concern*
  - *Significant non-recurring costs to develop parachute (~$100M)*
  - *Small NRE costs (~$1M)*

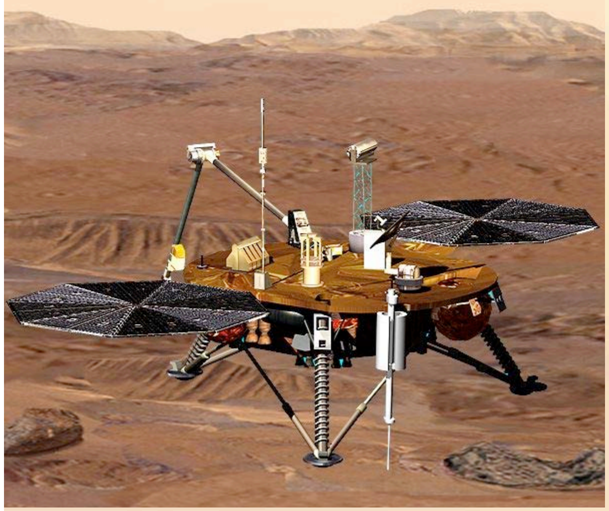
- *Orbit Insertion*
  - *Fully mitigates dust concern*
  - *Increased launch vehicle costs (~$100M per launch)*
  - *Increased cruise/insertion stage costs*
  - *Still need to develop new parachute to improve altitude capability*

Parachute is a cost effective solution for increased altitude capability

Thoughts on Common Static Landers

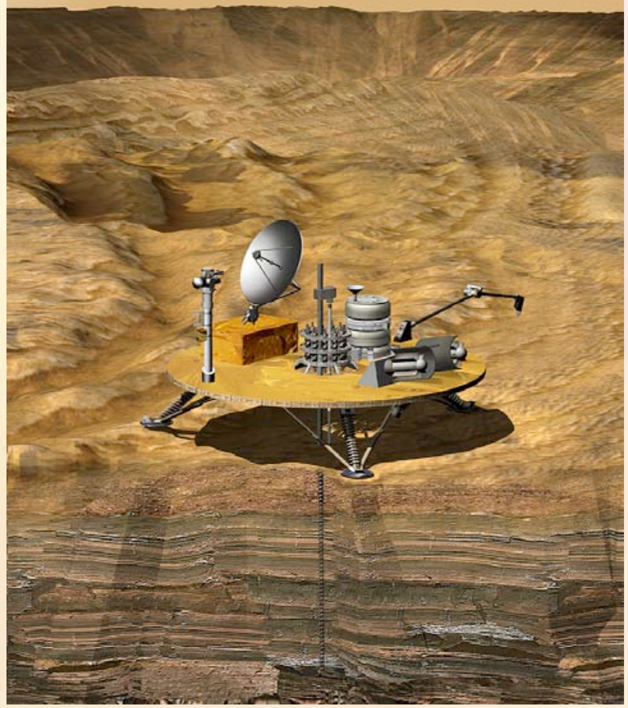
Opportunities for Static Lander Applications

Human Precursor Technology Test-beds (1-3)



Mars Sample Return (2)

Deep Drill Lander (1)

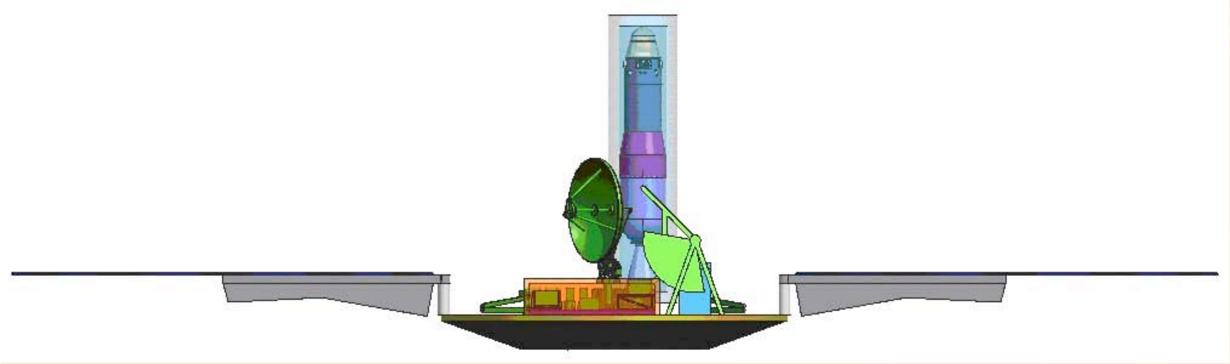


Mass for all applications ~ 1,000 - 1,200 Kg

Alternative Concepts for Mars Static Lander

Platform on Legs

- *Potential common elements*
  - *Mechanical platform and skycrane interface.*
  - *Avionics and telecom.*
  - *Dynamic testing with skycrane system (qualification).*
  - *Planetary protection implementation.*

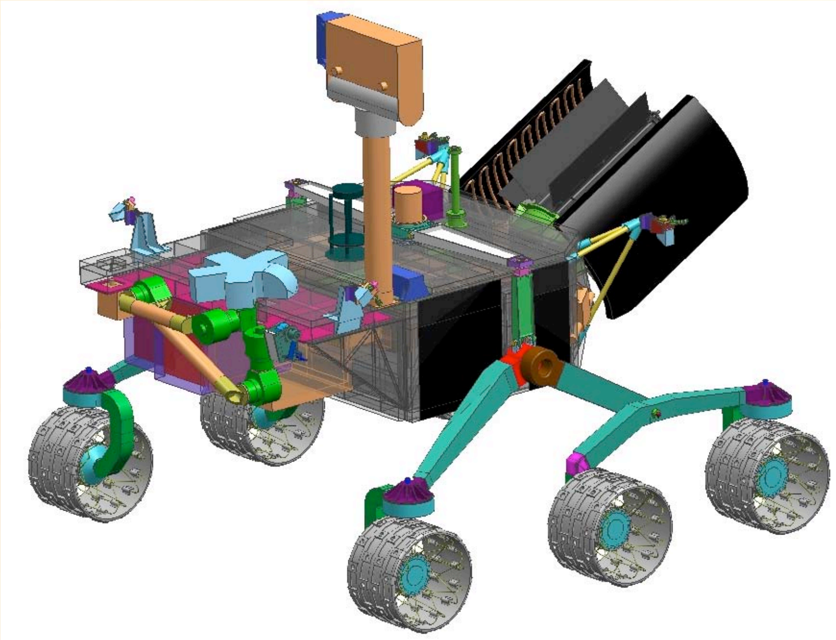


Pallet on Martian Surface

Thoughts on Common MSL-Class Rovers

What is MSL?

- 600kg
  - 65kg science payload
- 100 watt RTG
- Roving range: 10-20km



Repeat Opportunities for MSL-class Rover

- One or two of each of the following
  - MSL in 2009 or 2011
  - AFL mid-next decade
    - Will require more payload capacity (100kg?)
  - Possibly the mobile element of MSR

Planetary Protection

- MER was Category IV A
- MSL can be Category IV C
- MSR & AFL will likely need to be Category IV B
  - Same as Viking
- How much will planetary protection classification play into design and development of a common rover?
- Additional cost for Category IV B relative to Category IV C will be very significant

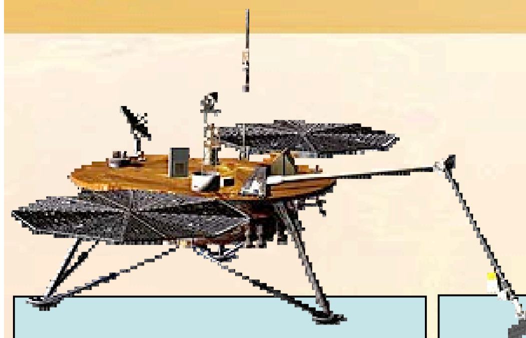
Thoughts on MSL/MSR Commonality

Anatomy of an MSR Mission

- Two identical landers each carrying
  - a platform to land on Mars,
  - a rover to get samples and bring back to the landed platform
  - a bowling ball size container to house the collected samples
  - a Mars Ascent Vehicle (MAV) to launch the sample canister into low Mars orbit

- One orbiter to capture the sample from Mars orbit and deposit into a Earth return vehicle

Range of MSR Rover Alternatives



Groundbreaking (no rover)	Single Entry Vehicle Lander, MAV, Fetch Rover	Dual Entry Vehicles Lander/MAV & MSL Reuse	All-Inclusive Rover
Delivered Mass: 1000 kg	Delivered Mass: 1300 kg	Lander/MAV Delivered Mass: 1000 kg Rover Mass 700kg	Delivered Mass: 1300 kg

MER Copy

MER Class

MSL Reuse

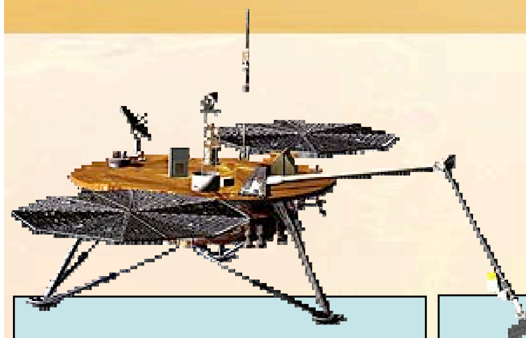
Rover Mass: ~200 kg

Why Not Build to Print MER Rover?

- Parts obsolescence will require some changes
  - Cassini ASIC
  - RAD 6K computer
- Design optimized to the Athena payload, and a different payload will require some design changes
  - Design accommodates 5 kg payload mass and 15 kg payload support
  - Arm accommodates 4 instruments at ~ 1.5 kg
  - Mast is fore-optics for Thermal Emission Spectrometer which is contained inside the rover body
- Rover mechanical design is highly integrated - extremely brittle given even small changes in “payload” (science, avionics, power, telecom)
  - Volume margin is minimal

Highly Optimized for the Volume Available

Range of MSR Rover Alternatives



Groundbreaking (no rover)	Single Entry Vehicle Lander, MAV, Fetch Rover	Dual Entry Vehicles Lander/MAV & MSL Reuse	All-Inclusive Rover
Delivered Mass: 1000 kg	Delivered Mass: 1300 kg	Lander/MAV Delivered Mass: 1000 kg Rover Mass 700kg	Delivered Mass: 1300 kg

?

MER Copy

MER Class

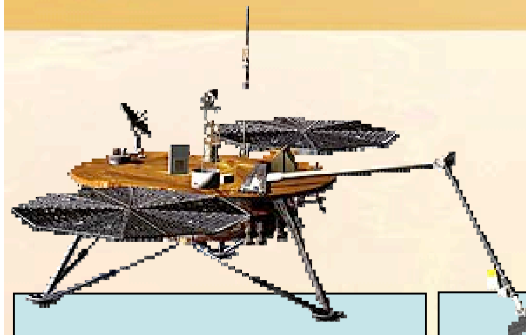
MSL Reuse

Rover Mass: ~200 kg

Altitude Capability w/Improved Parachute

- *Common EDL designed for 1300 kg delivery requirement*
- *Dust degraded performance assumed ($\tau = 3.0$)*
- *2013 opportunity*

Range of MSR Rover Alternatives



<u>Groundbreaking</u>
(no rover)

Delivered Mass: 1000 kg

<u>Single Entry Vehicle</u>
Lander, MAV,
Fetch Rover

Delivered Mass: 1300 kg

<u>MER Copy</u> ?

<u>MER Class</u>

~~<u>MSL Reuse</u>~~

Rover Mass: ~200 kg

<u>Dual Entry Vehicles</u>
Lander/MAV &
MSL Reuse

Lander/MAV Delivered Mass: 1000 kg
Rover Mass 700kg

<u>All-Inclusive Rover</u>

Delivered Mass: 1300 kg

Rover Options

- *MER Class (200 kg)*
  - *Payload mass capability: 20-30 kg*
  - *Solar powered, lifetime and latitude constrained*
  - *Substantial non-recurring engineering required*
  - *Design can be optimized for PP and organic cleanliness issues*

- *MSL Reuse (600kg)*
  - *Payload mass capability: 65 kg*
  - *RTG powered, full latitude and lifetime access*
  - *NRE limited to payload changes*
  - *Impact of PP and organic cleanliness requirements is TBD*

- *All-Inclusive Rover (1,300 kg)*
  - *Science payload mass capability: 65 kg*
  - *Capable of carrying MAV & MAV launch equipment*
  - *RTG powered, full latitude and lifetime access*
  - *Design can be optimized for PP and organic cleanliness issues*

Elements of MSR

- *Orbiter*
  - *Utilize elements of common orbiter*
- *Cruise/EDL system*
  - *Use common EDL system*
- *Lander*
  - *Common static lander (possibly same as MHP first flight)*
- *Mars Ascent Vehicle*
  - *MSR developed*
- *Earth Entry Vehicle*
  - *MSR developed*
- *Rover*
  - *Several options*

MSR Conclusions

- *Groundbreaking MSR is lowest cost option, but is not acceptable to science*
- *Reusing MSL rover for MSR requires more costly dual entry vehicle architecture*
- *Single Entry Fetch Rover and All-Inclusive rover are viable*
  - *Fetch rover capabilities needs to be assessed by science community*
  - *Need cost trade between All-Inclusive rover & common lander development*
- *MSL and all MSR options can make use of common EDL system*
  - *Commonality benefits depends upon design stability & discipline*
  - *Common system design will mature through first several flights*
  - *Near term missions should assume substantial EDL system engineering & validation efforts despite commonality*

Commonality Considerations

- Future Mars robotic missions can make use of common elements
  - EDL
  - Orbiter
  - Lander

- Potential commonality for rovers
  - Commonality between MSL & MSR rovers exists, but might be limited

- Benefits of commonality depend on program architecture and frequency of reuse

- Development of new parachute system critical to future Mars robotic program

Back up slides

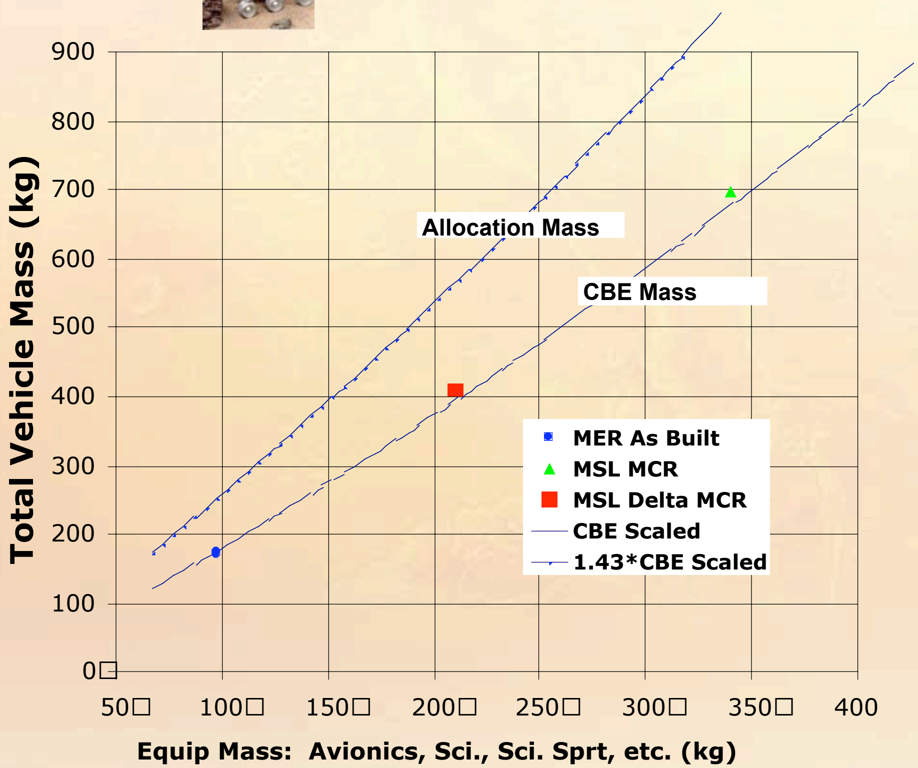
Why Not Reuse MER Airbag EDL Again?

- *MER was a ballistic (rather than guided) entry*
  - *With zero delivery error at entry, landing ellipse major axis ~ 60 - 70 km, minor axis ~10 km (99%)*
    - *Expected 2009-2016 approach nav errors of few km (99%) should only increase this by 10 km or so*
  - *Increase in dust tau associated with dust storms reduces atmospheric density, but also increases atmospheric density uncertainty, which increases landing error ellipse size*
- *MER EDL altitude capability below –1.3 km MOLA for 2003 atmospheric conditions*

Parachute Development Approach

- Start rapid development program for improved supersonic parachute
  - Complete supersonic qualification in time for MSL '09 launch
    - Likely to be completed ~ 1 year prior to launch
  - Need near-term decision and aggressive start up
- Near term activities include subscale wind tunnel tests to down select parachute technology, development of balloon launch and test article infrastructure, and selection of parachute subcontractor
  - Aim for first development flight test ~ 18 months
  - Provide opportunity for three test/retest opportunities
- Qualify parachute design for subsonic conditions to provide backup for supersonic qualification problems

MER was 180kg why is MSL 600kg?



- MER to MSL Equip Growth (240kg):
  - Power: ~30 kg
  - Thermal ~20 kg
  - Avionics ~10 kg
  - Sci instruments ~40 kg
  - Sci accommodation ~20 kg

  Sub-total + 120kg
  - Structure/mobility "wrap mass" ~ 120kg
- MSL Mass
  - By analogy to MER =180+240 = 420kg
  - CBE: 410 kg
    - Structure/Mobility: 200 kg CBE
    - Equipment: 210 kg CBE
  - *Mass + margin = 410Kg * 1.43 = 586Kg*
  - *Project allocation = 600 kg*

- Analysis of flight Rovers indicates that the mass of the structure and mobility consumes approximately 45%-50% of the total mass